MIPS Reduces Headform Kinematics Across a Range of Impact Speeds

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I. INTRODUCTION

The head experiences both linear and angular accelerations during most impacts. The expanded polystyrene (EPS) liners in typical bicycle helmets are designed to crush and crack during an impact and are effective at reducing the peak linear accelerations and increasing the impact duration. More recently, systems designed to reduce rotational head kinematics, which are more directly related to brain strain and concussion injury risk [1], became available to consumers. One example of these systems is the Multi-directional Impact Protection System (MIPS), which is designed to create a slip plane between the head and EPS liner. Prior studies have quantified headform kinematics in oblique impacts with and without MIPS about a single axis [2] and reported kinematics averaged across six impact orientations without separating data with MIPS [3]. Here we sought to quantify the effects of MIPS (present vs. absent) and headform condition (bare skin vs. stocking-covered) on peak headform kinematics in two impact orientations over a range of impact speeds. We hypothesised that MIPS would lower the peak headform kinematics at all speeds compared to no-MIPS for both the bare and stocking conditions, and that the reduction for MIPS would be larger than the reduction due to stockings alone.

II. METHODS

Specialized Echelon helmets (size L) were fit to a 50^{th}%ile Hybrid III headform (4.72kg) either covered in two layers of nylon stockings or left bare. The helmet positioning index (HPI) was set to 90mm and the ring-fit system was tightened until slight resistance was met. The chinstrap was adjusted so that 2-3 fingers fit comfortably between the buckle and headform, and low-density foam was then inserted into this space. The headform and helmet were inverted and placed on a U-shaped freefalling trolley (X and Y-axes ±1° of horizontal) that fell past a 45° anvil covered with 40-grit sandpaper. The headform was oriented to produce rotations about either the X or Y-axis (Figure 1b,c) at impact speeds of ~4.2, 5.1, 6.2, 7.2m/s. Each helmet experienced at most two impacts—one about each rotation axis—separated by 135mm. A cantilevred arm holding the headform in place during the freefall released prior to impact and a slack tether attached to the headform prevented a secondary impact. To ensure consistent placement of the headform and helmet, an image of the initial headform position with a no-MIPS helmet was captured and then overlaid on a live image of the MIPS condition at 50% transparency. A helmet with and without MIPS was tested at each impact condition and speed for a total of 32 impacts. Six degree-of-freedom headform kinematics were captured with a 3-2-2-2 accelerometer array (2000g, TE Connectivity, Schaffhausen, Switzerland; r_x=56mm, r_y=48mm, r_z=81mm) sampled at 50kHz and high-speed video recorded at 1kHz (Chronos 1.4, Krontech, Vancouver, BC, Canada). Peak resultant linear acceleration (PLA), angular acceleration (PAA) and angular velocity (PAV) were extracted/computed from the filtered data (CFC 180) and peak amplitudes were normalised to the no-MIPS, bare-head condition (Fig. 1a,d). The effects of MIPS and headform condition on PLA, PAA, and PAV were assessed separately for each rotation axis using a general linear model with impact speed as a covariate (α=0.5, Minitab 19, State College, PA, USA). Brain injury criterion (BrIC) was also computed and similarly assessed [4].

III. INITIAL FINDINGS

Impact speeds were 4.15 ± 0.06, 5.16 ± 0.06, 6.26 ± 0.04, 7.21 ± 0.03m/s. For X-axis rotations, all main effects were statistically significant for PLA, PAA and PAV ($p<0.001$) except for the headform condition for PLA ($p=0.055$; Figure 1a). The interaction term (MIPS×headform-condition) was only significant for PAV ($p=0.042$). For Y-axis rotations, all main effects were significant for PAA and PAV. Neither MIPS/no-MIPS ($p=0.170$) nor headform condition ($p=0.873$) were significant for PLA. MIPS reduced peak kinematics and BrIC more than just the two layers of stockings alone.

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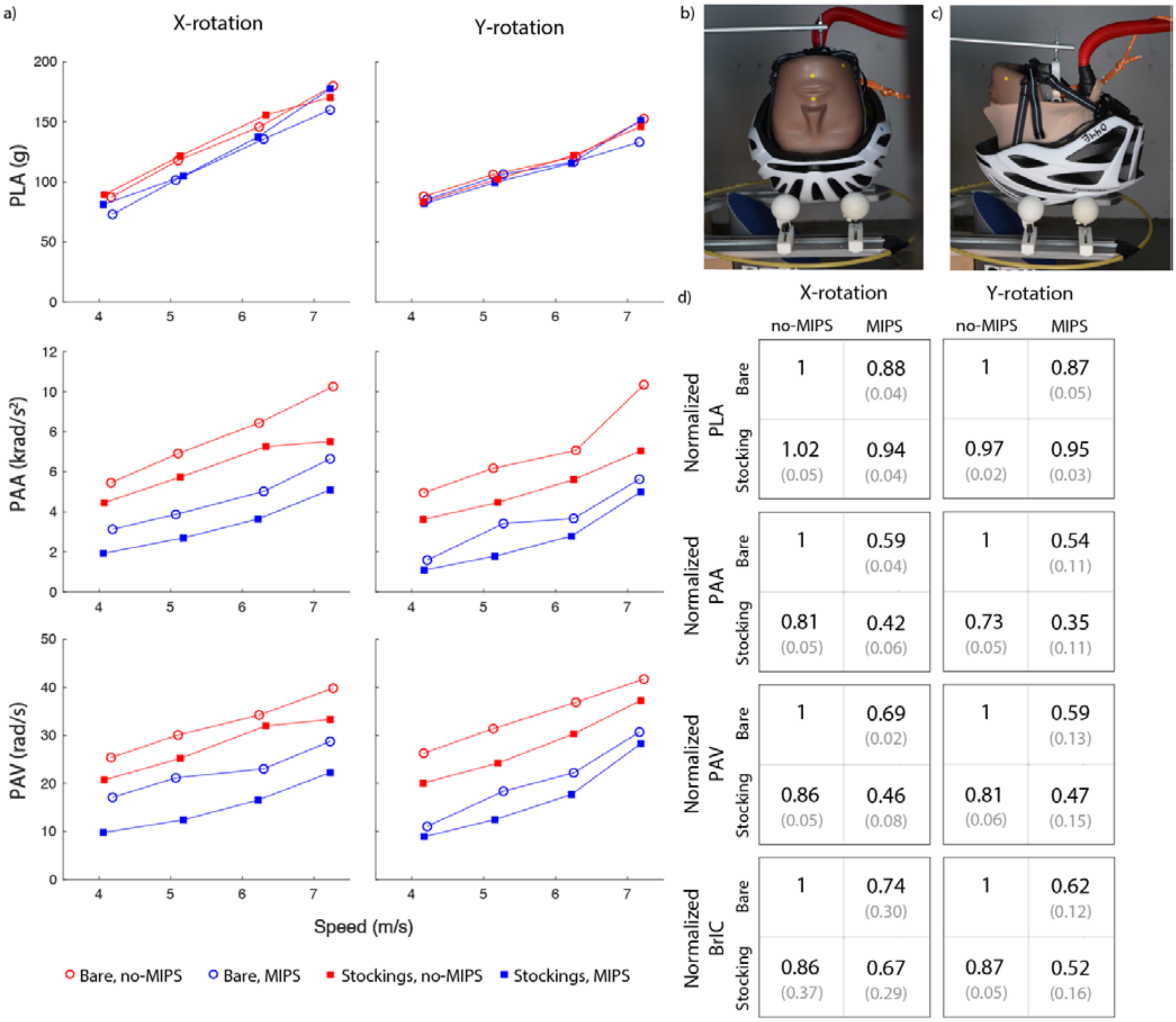

Fig. 1. a) PLA, PAA, and PAV for all conditions across the four impact speeds. Headform orientation for b) X-axis rotation, bare headform and c) Y-axis rotation, stocking-covered headform. d) Average (SD) amplitudes of all metrics normalised to the bare, no-MIPS condition.

IV. DISCUSSION

This study examined the effects of MIPS (present, absent) and headform condition (bare, stockings) on peak resultant headform kinematics during oblique impacts about the X and Y axes over four impact speeds. MIPS significantly reduced PAA and PAV across all impact speeds for both the bare and stocking conditions. Stockings alone, i.e., no MIPS, also reduced the rotational kinematics and BrIC compared to the bare condition without MIPS, and adding stockings to the MIPS condition further reduced PAV and BrIC in both rotation directions.

To compare our results with [2], who tested MIPS at 4.8 and 6.2 m/s, we linearly interpolated our peak kinematics from 4.2 and 5.2 m/s to 4.8 m/s for the 45-degree anvil. For the 4.8m/s Y-rotation impact, MIPS reduced PAV 38% in [2] compared to 52% in the current study. For the 6.2m/s Y-rotation impact, MIPS reduced PAV 23% in [2] compared to 40% in the current study. Differences in test set-up (their Hybrid III neck was rigidly attached to a falling trolley vs. our freefalling headform) and helmet model may contribute to these differences in PAV reductions. We were unable to compare our results to [3] because they averaged kinematics over six impact orientations and data from MIPS helmets were not separated.

Our study was limited to a single helmet make/model/size and only one impact for each test condition at each impact speed. Future work should include repeated impacts and examine the effect of human hair at the interface between the headform and the helmet.

V. REFERENCES

[1] Kleiven, Stapp, 2007.
[2] Bliven, AAP, 2019.
[3] Bland, ABME, 2019.
[4] Takhounts, Stapp, 2013